International Journal of Electrical and
Electronics Engineering Research (IJEEER)
ISSN(P): 2250-155X; ISSN(E): 2278-943X
Vol. 6, Issue 2, Apr 2016, 13-26

A NOVEL TECHNIQUE FOR REDUCING THE FAULT CURRENT AND OVER VOLTAGE IN ELECTRICAL POWER DISTRIBUTED SYSTEM AND ENHANCING THE SECURITY THROUGH AN ACTIVE TYPE SFCL

PRABHAKARA SHARMA. P, SUREKA VADDE & V. N. MURTHY. M

Department of Electrical & Electronics Engineering, KHIT, Guntur, Andhra Pradesh, India

ABSTRACT

To achieve both operational reliability and financial profitability, it has become clear that more efficient utilization and control of the existing power system infrastructure is required. Improved utilization and performance of the existing power system is obtained through the application of advanced control technologies. Control based equipment, i.e. Super Conducting Fault Current Limiter (SFCL) provides proven technical solutions to face the new operating challenges being presented today in the Electrical Power Systems to reduce the fault current effects and over voltages in the distribution network.

Over Voltages and Over Currents is the common and undesirable power quality phenomenon in the distribution systems which put sensitive loads under the risk. Super Conducting Fault Current Limiter (SFCL) can provide the most commercial solution to mitigate these voltages by injecting voltage into the system. This paper presents the application of on power distribution systems for Super Conducting Fault Current Limiter (SFCL) mitigation of voltage sags at critical loads. In this strategy, an overview of the SFCL, its functions, configurations, components, compensating strategies and control methods are reviewed along with the device capabilities and limitations. The proposed control scheme is very effective to detect any disturbance in power systems.

SFCL is modeled using MATLAB / SIMULINK Software tools to represent the quench and recovery characteristics based on the experimental results.

KEYWORDS: SFCL, MATLAB / SIMULINK

Received: Feb 15, 2016; **Accepted:** Feb 26, 2016; **Published:** Mar 02, 2016; **Paper Id.:** IJEEERAPR201602

Original Article

INTRODUCTION

The Power System is an interconnection of generating units to load centers through high voltage electric transmission lines and in general is mechanically controlled. With the ongoing expansion and growth of the electric utility industry, including deregulation in many countries, numerous changes are continuously being introduced to predictable business. Although electricity is a highly engineered product, it is increasingly being considered and handled as a commodity. Thus, transmission systems are being pushed closer to their stability and thermal limits while the focus on the quality of power delivered is greater than ever. In the evolving utility environment, financial and market forces are, and will continue to, demand a more optimal and profitable operation of the power system with respect to generation, transmission, and distribution. Now, more than ever, advanced technologies are paramount for the reliable and secure operation of power systems. To achieve both operational reliability and financial profitability, it has become clear that more efficient utilization and control of the existing transmission

system infrastructure is required. Improved utilization of the existing power system is provided through the application of advanced control technologies.

Now a days, modern industrial devices are mostly based on electronic devices such as programmable logic controllers and electronic drives. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problems such as voltage sags, swells and harmonics. Voltage support at a load can be achieved by reactive power injection at the load point of common coupling. The common method for this is to install mechanically switched shunt capacitors in the primary terminal of the distribution transformer. In today circumstances, rapid development of power network cause the fault current of the system increased greatly. The levels of fault current in many places have often exceeded the withstand capacity of existing power system equipment. As implication to this matter, security, stability and reliability of power system will be negatively affected. Thus, limiting the fault current of the power system to a safe level can greatly reduce the risk of failure to the power system equipment due to high fault current flowing through the system. Because of that, there is no surprise to fault current limiting technology has become a hot spot of fault protection research since this technology is to limit the fault current to a low level.

In power system design view, limiting the fault current to a low level can reduce the design capacity of some electrical equipment in the power system. This will lead to the reduction to the investment cost for high capacity circuit breakers and construction of new transmission line. Consequently, from both technical and economical points of view, fault current limiting technology for reducing short circuit current is needed. The distribution of a power system with DG units it's induced over voltages & fault currents under abnormal conditions should be consider into account seriously so in consideration that applying "Superconducting Fault Current Limiter" may be a feasible solution.

POWER GRIDS OF THE FUTURE

An increasingly decentralized supply of power, higher power flows and the present backlog of investment in equipment will require stronger adaptations (i.e. like SFCL) to the power network in the coming years. In this context, high short-circuit currents play an essential role. For example, in power networks short circuits can arise due to lightning strikes or failures of system components and of power lines, resulting in high fault currents. These cause extremely high dynamic and thermal loads which all system components of the power network must resist.

As the global population grows, power engineers must establish alternative energy sources to gradually replace fossil-fuelled sources like coal and oil, which emit greenhouse gases that are widely believed to result in climate change. Energy supplies for the future are facing a severe shortage and require increased levels of security.

CONSTRUCTION AND OPERATION OF THE ACTIVE SFCL THEORETICAL ANALYSIS

The figure 1 Shows the circuit construction of the voltage compensation of single-phase active SFCL, which is consists of a voltage-type PWM converter and an air-core superconducting transformer. The self-inductance of two superconducting windings are L_{s1} and L_{s2} and the mutual inductance is M_s. The circuit impedance is Z_1 and the load impedance is Z_2. C_d and L_d are used for filtering of harmonics of high order caused by the converter. Hence the voltage-type converter's capability of controlling power exchange is implemented by regulating the voltage of AC side, the converter can be thought as a controlled voltage source up.

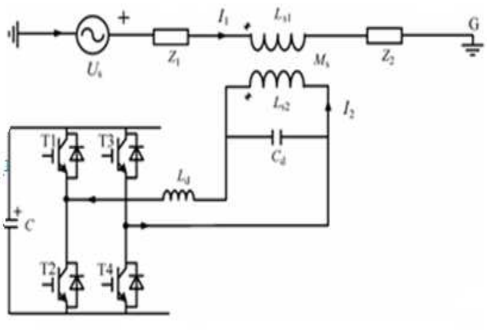

Figure 1: Circuit Structure of Single Phase Voltage Compensation Type Active SFCL

In general (no fault) state, the current I_2 is injected in to the transformer secondary winding it will be controlled to keep a certain value, then the magnetic field in the air-core can be compensated to zero, so the active SFCL will have no influence on the main circuit. When the fault is detected, the injected current will be timely adjusted in phase angle or amplitude, so as to control the superconducting transformer's primary voltage which is in series with the main circuit and further the fault current can be suppressed to some extent. By the losses of the transformer is neglected.

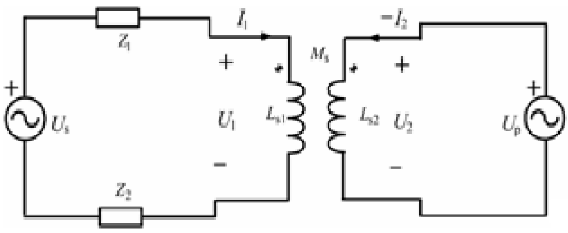

Figure 2: Equivalent Circuit of Single Phase Voltage Compensation Type Active SFCL

The given below suggested SFCL's regulating mode is explained. In general state, these equations can be obtained

$$\dot{U_s} = \dot{I_1}(Z_1 + Z_2) + j\omega\, L_{s1}\, \dot{I_1} - j\omega M_s \dot{I_2}$$

$$\dot{U_p} = j\omega M_s \dot{I_1} - j\omega L_{s2} \dot{I_2}$$

Controlling I_2 to make $j\omega\, L_{s1}\ \dot{I_1} - j\omega M_s \dot{I_2} = 0$ and the primary voltage U_1 will be regulated to zero. Then the equivalent limiting impedance Z_{SFCL} is = 0

($Z_{SFCL} = U_1 / I_1$) and I_2 can be set as $\dot{I_2}\ U_s$ under fault condition (Z_2 is shorted) the main current will rise from I_1 to I_{1f} and the primary voltage will increase to U_{1f}.

$$\dot{I_{1f}} = \frac{(\dot{U_s} + j\omega M_s \dot{I_2})}{(Z_1 + j\omega\, L_{s1})}$$

$$\dot{U_{1f}} = j\omega L_{s1} \dot{I_{1f}} - j\omega M_s \dot{I_2}$$

$$\dot{U_{1f}} = \frac{\dot{U_s}\,(J\omega L_{s1}) - \dot{I_2}\,\dot{Z_1}\,(J\omega M_s)}{(Z_1 + j\omega\, L_{s1})}$$

The Current-Limiting Impedance Z_{SFCL} can be controlled in:

$$Z_{SFCL} = \frac{\dot{U_{1f}}}{\dot{I_{1f}}} = J\omega L_{s1} - \frac{j\omega M_s \dot{I_2}\,(Z_1 + j\omega\, L_{s1})}{(\dot{U_s} + j\omega\, M_s \dot{I_a})}$$

THE SFCL APPLYING INTO A DISTRIBUTION NETWORK WITH DG

The figure 3 shows the application of the active SFCL in a distribution network with multiple DG units, and the buses B-E are the DG units' probable installation locations.

When a single-phase grounded fault occurs in the feeder line 1 (phase A, k1 point), the SFCL's mode1 can be triggered automatically, and the fault current's rising rate can be timely controlled. Along with the switching mode its amplitude can be limited further. In consideration of the SFCL's effects on the induced overvoltage, the qualitative analysis is presented.

In order to calculate the overvoltage's in the other two phases (phase B and phase C), the complex sequence networks and symmetrical component method can be used and the coefficient of grounding G under this condition can be expressed as G = −1.5m/ (2 + m) ± j√3/2), where m $=X_0/X_1$, and X_0 is the distribution network's zero-sequence reactance, X_1 is the positive-sequence reactance [16]. Further, the amplitudes of the B-phase and C-phase overvoltage's can be described as:

$$U_{BO} = U_{CO} = \sqrt{3}\left|\frac{\sqrt{G^2+G+1}}{G+2}\right| U_{AN}$$

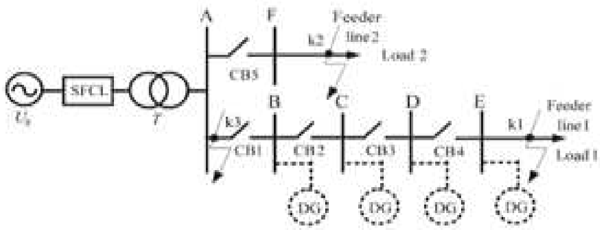

Figure 3: Application of the Active SFCL in a Distribution System with DG Units

The Current-Limiting Impedance Z_{SFCL} can be controlled in:

$$Z_{SFCL} = \frac{\dot{U_{1f}}}{\dot{I_{1f}}} = J\omega L_{s1} - \frac{j\omega M_S \dot{I_2}\,(Z_1 + j\omega\, L_{S1})}{(\dot{U_S} + j\omega\, M_S \dot{I_a})}$$

The air-core superconducting transformer has many features, such as iron losses absence and magnetic saturation, and it has more flexibility of reduction in size, weight and harmonic than the conventional iron-core superconducting transformer [11], [12]. Compared to the iron-core, the air-core can be more suitable for functioning as a shunt reactor because of the large magnetizing current [13], and it can also be applied in an inductive pulsed power supply to decrease energy loss for larger pulsed current and higher energy transfer efficiency [14], [15]. There is no existence of transformer saturation in the air-core, and using it can ensure the linearity of Z_{SFCL} well.

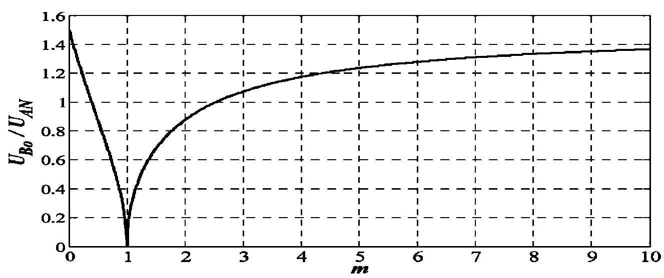

Figure 4: Relationship between Reactance Ratio (m) and B-Phase Overvoltage

The figure 4. It indicates the relationship between the B-phase overvoltage and reactance ratio m. It should be pointed out that for the distribution system with isolated neutral-point the reactance ratio m is usually larger than four. Compared with the condition without SFCL, the introduction of the active SFCL will increase the power distribution network's positive-sequence reactance under fault state. Since $X_0 /(X_1 + Z_{SFCL}) < X_0 /X_1$, installing the active SFCL can help to reduce the ratio m and then, from the point of the view of applying this suggested device, it can lower the overvoltage's amplitude and improve the system's safety and reliability.

Furthermore, taking into account the changes in the locations of the DG units connected into the distribution system, the DG units' injection capacities and the fault positions, the specific effects of the SFCL on the fault current and overvoltage may be different, and they are all imitated in the simulation analysis.

OVERVOLTAGE-SUPPRESSING CHARACTERISTICS OF THE SFCL

Supposing that the injection capacity of each DG is about 80% of the load capacity (load 1), and the fault location is k1 point (phase-A is shorted), and the fault time is t = 0.2 s, the simulation is done when the DG2 is respectively installed in the buses C, D, and E, and the three cases are named as case I, II, and III. Figure 3. shows the SFCL's overvoltage-suppressing characteristics and the waveforms with and without the SFCL are both listed. For the cases I, II, and III, the overvoltage's peak amplitude without SFCL will be respectively 1.14, 1.23, 1.29 times of normal value, and once the active SFCL is applied, the corresponding times will drop to 1.08, 1.17 and 1.2.

During the study of the influence of the DG's injection capacity on the overvoltage's amplitude, it is assumed that the adjustable range of each DG unit's injection capacity is about 70% to 100% of the load capacity (load 1), the two DG units are located in the buses B and E, and the other fault conditions are unchanged, Tabular Representation 1. shows the overvoltage's amplitude characteristics under this background.

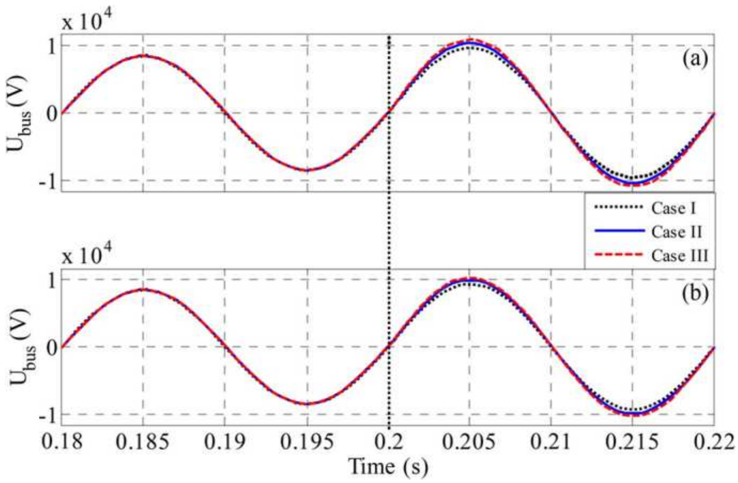

Figure 5: SFCL's Overvoltage-Suppressing Characteristics

Along with the increase of the DG's injection capacity, the overvoltage will be accordingly rise, and once the injection capacity is equal or greater than 90% of the load capacity, the overvoltage will exceed acceptable limit (1.3 times). Never the-less, if the active SFCL is put into use, the limit-exceeding problem can be solved effectively.

Table 1: Overvoltage's Amplitude Characteristics under Different Injection Capacities of DG units

GD's Injection Capacity	Ratio of Overvoltage to Normal Voltage	
	Without SFCL	With the Active SFCL
70%	1.25	1.19
80%	1.29	1.2
90%	1.33	1.22
100%	1.38	1.29

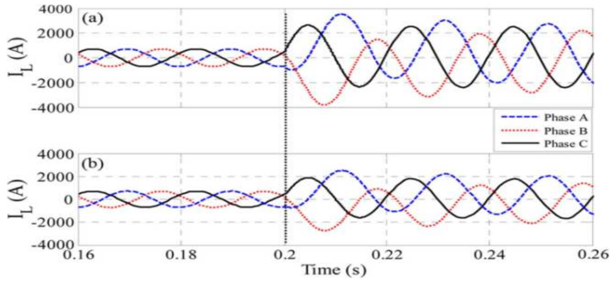

Figure 6: Line Current Waveforms when the Three-phase Short-circuit Occur at k3 point. (a) Without SFCL and (b) With the active SFCL

CURRENT-LIMITING CHARACTERISTICS OF THE SFCL

By observing the voltage compensation type active SFCL's installation location, it can be found out that this device's current-limiting function should mainly reflect in suppressing the line current through the distribution transformer. There- upon, to estimate the most serious fault characteristics, the following conditions are designed the injection capacity of each DG is about 100% of the load capacity load 1 and the two DG units are separately installed in the buses B and E. Moreover, the three-phase fault occurs at K1, K2, and K3 points respectively and the fault occurring time is t = 0.2s. Hereby, the line current characteristics are imitated.

As shown in Figure 6. It indicates the line current waveforms with and without the active SFCL when the three-phase short- circuit occurs at K3 point. After installing the active SFCL, the first peak value of the fault currents i_{Af} , i_{Bf} , i_{Cf} can be limited to 2.51 kA, 2.69 kA, 1.88 kA, respectively, in contrast with 3.62 kA, 3.81 kA, 2.74 kA under the condition without SFCL. The reduction rate of the expected fault currents will be 30.7%, 29.4%, 31.4%, respectively.

Figure 6 Shows the SFCL's current-limiting performances when the fault location is respectively K1 point and K2 point (selecting the phase-A current for an evaluation).

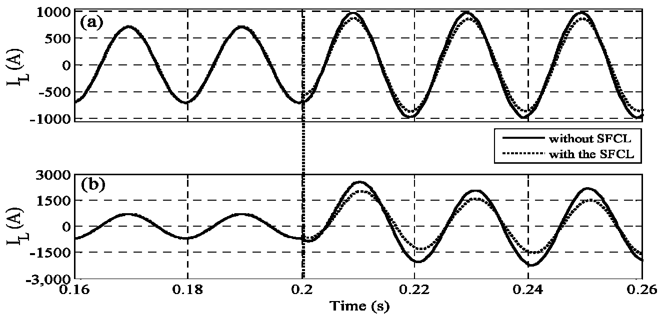

Figure 7: Active SFCL's Current-Limiting Performances under Different Fault Locations. (a) k1 point and (b) k2 point

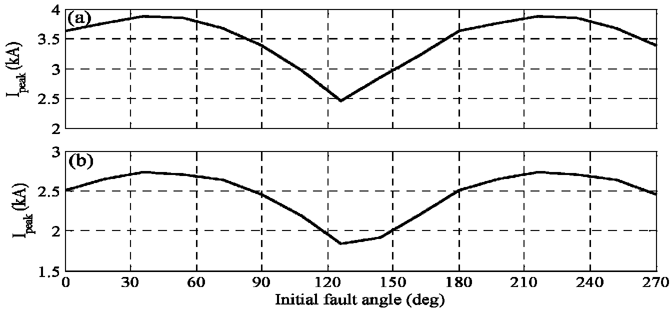

Figure 8: Influence of Initial Fault Angle on the Peak Amplitude of the A-Phase Short-Circuits Current. (a) Without SFCL and (b) With the Active SFCL

The active SFCL, the influence of initial fault angle on the peak amplitude of the A-phase short-circuit current is analyzed in Figure 7. Where the fault location is K3 point. It can be seen that, under the conditions with and without the SFCL, the short- circuit current's peak amplitude will be smallest when the fault angle is about 130°. At this fault angle, the power distribution system can immediately achieve the steady transition from normal state to fault state.

SIMULATION STUDIES

Simulation Results and Analysis

(1-Ø & 3-Ø SYSTEM WITH AND WITHOUT SFCL**)**

In this paper simulation studies of distribution system with and without Super Conducting Fault Current Limiter (SFCL) with load current measurement and source current detection will be presented.

- **Modeling of Single Phase Distribution System without Super Conducting Fault Current Limiter (SFCL*)***

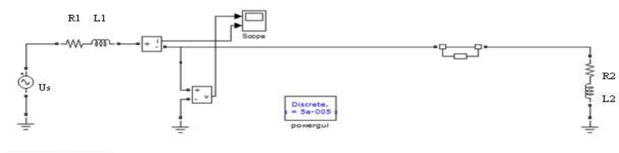

Figure 9: Single Phase Distribution System without SFCL

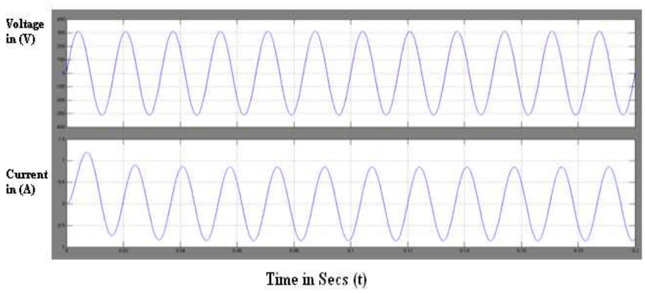

Figure 10: Single Phase Voltage & Current Waveform without SFCL Model

- **Total Harmonic Distortion for Single Phase without SFCL**

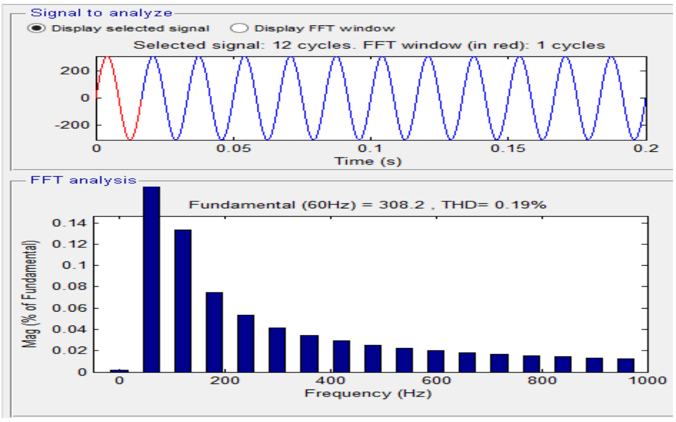

Figure 11: Single Phase THD Analysis without Super Conducting Fault Current Limiter

- **Modeling of Three Phase Distribution System without SFCL**

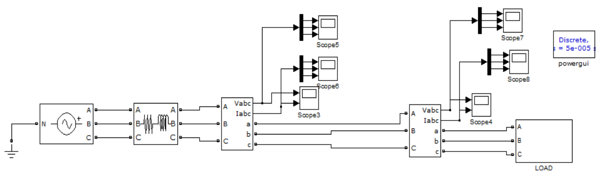

Figure 12: Three Phase Distribution System without SFCL

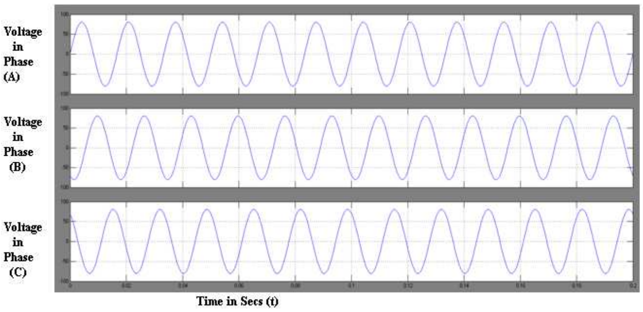

Figure 13: Three Phase Voltage Waveform without SFCL Model

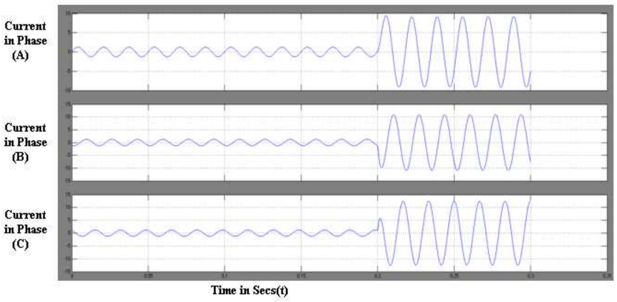

Figure 14: Three Phase Current Waveform without SFCL Model

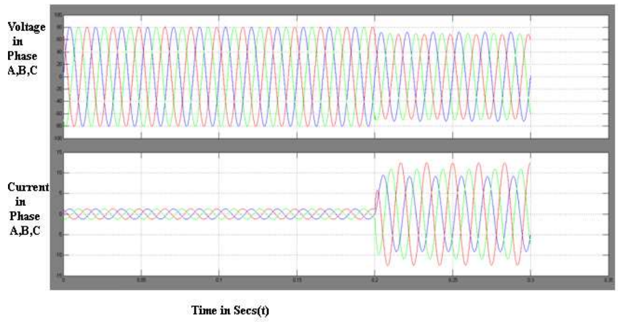

Figure 15: Three Phase Voltage & Current Waveform without SFCL Model

- **Total Harmonic Distortion for Three Phases without SFCL**

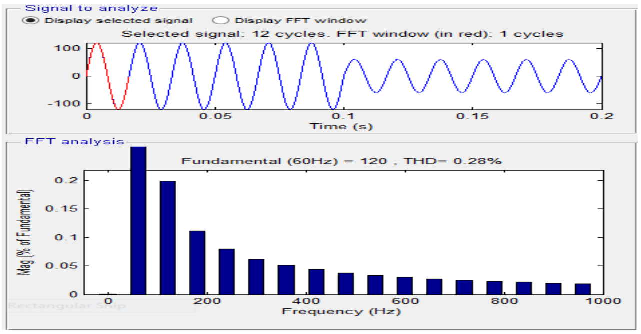

Figure 16: Three Phase THD Analysis without Super Conducting Fault Current Limiter

DISCUSSIONS ON TOTAL HARMONIC DISTORTION

Figure 16 It is very clear that the THD is 0.28% in three phase system without implementing the SFCL Model in the Distribution System.

- **Modeling of Single Phase Distribution System with Super Conducting Fault Current Limiter (SFCL)**

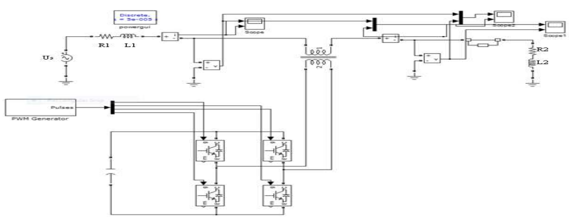

Figure 17: Single Phase Distribution System with SFCL

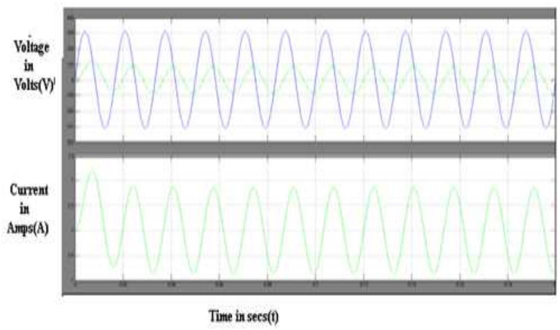

Figure 18: Single Phase Source Voltage & Current Wave Forms with SFCL Model

- **Total Harmonic Distortion for Single Phase with SFCL**

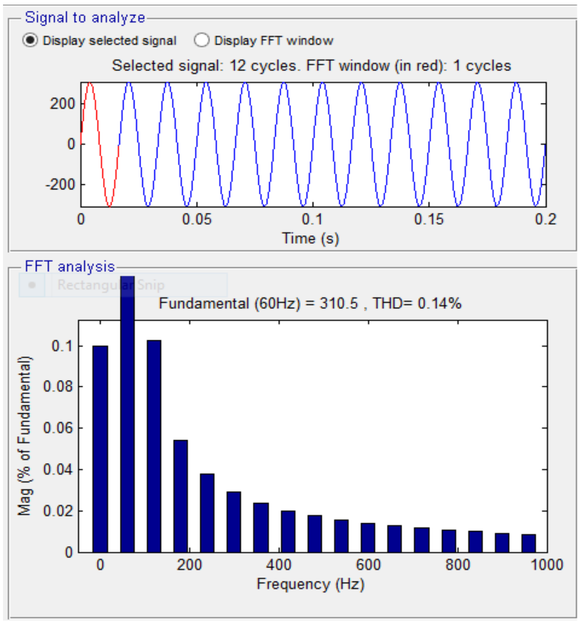

Figure 19: Single Phase THD Analysis with Super Conducting Fault Current Limiter

- **Modeling of Three Phase Distribution System without SFCL**

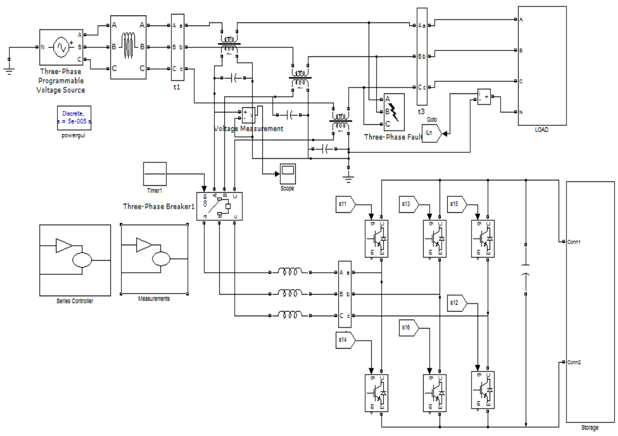

Figure 20: Three Phase Distribution System with SFCL

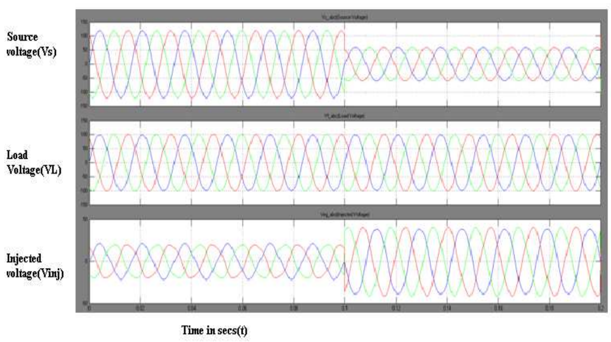

Figure 21: Three Phase Source & Load Voltage Waveform with SFCL

- **Total Harmonic Distortion for Three Phases with SFCL**

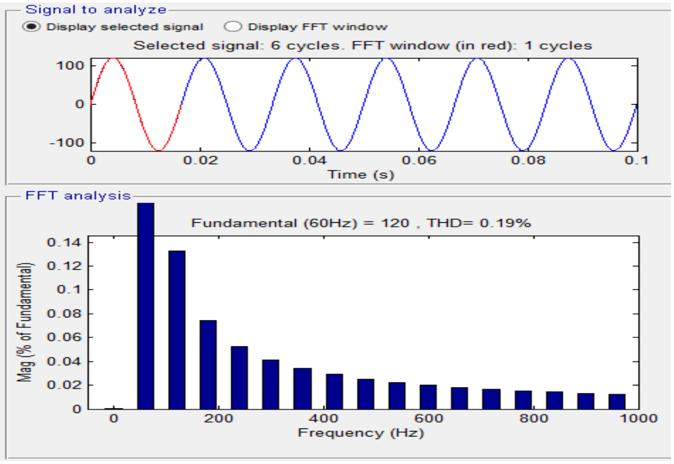

Figure 22: Three Phase THD Analysis with Super Conducting Fault Current Limiter

Analysis on Total Harmonic Distortion

Table 2

S. No	Without SFCL	With SFCL
1	Single Phase THD = 0.19	Single Phase THD = 0.14
2	Three Phase THD = 0.28	Three Phase THD = 0.19

CONCLUSIONS

The main contribution of this paper is a structured survey on reducing the fault currents in the distribution system. For the power frequency overvoltage caused by single-phase and three-phase faults the active SFCL can help to reduce the overvoltage's amplitude and avoid damaging the relevant electrical power distributed system.

The weak point in the distribution system which commonly undergoes single-phase and three phase faults which is the most harmful effect depending on the symmetrical components can be least limited by Super Conducting Fault Current Limiter. The structure and working principle of several SFCLs which perform high in the actual power grid such as resistive type, shielded-core type, and saturated iron core type are analyzed. The SFCL can increase the resistance effectively limit the amplitude of short-circuit current instantly so as to achieve the purpose of protecting the distribution system.

For purpose of quantitatively evaluating the current-limiting and overvoltage-suppressing characteristics of the active SFCL, the distribution system with DG units and the SFCL, is created and proposed in the simulation of SFCL using SIMULINK in MATLAB. Based on the Simulation carried out, it is clear that a SFCL can tackle over-voltages and Fault Currents when protecting sensitive loads.

With the progress of Super Conducting Technology and Super Conducting materials research and the developments of Power Electronics Technology, Super Conducting Fault Current Limiters (SFCL) will bring new thinking for Current-Limiting Technology of Power System This Thesis also gives useful knowledge for the researchers to develop a new design of SFCL for voltage disturbances in electrical system. Through the survey of SFCL applications, this work concludes that the trends of SFCL through the years are still assumed as a powerful area of research.

REFERENCES

1. *Reducing the Fault Current and Overvoltage in a Distribution System With Distributed Generation Units Through an Active Type SFCL - Lei Chen, Member, IEEE, Changhong Deng, Fang Guo, Yuejin Tang, Jing Shi, and Li Ren.*
2. *S. Conti, "Analysis of distribution network protection issues in presence of dispersed generation," Elect. Power Syst. Res., vol. 79, no. 1, pp. 49–56, Jan. 2009.*
3. *A. S. Emhemed, R. M. Tumilty, N. K. Singh, G. M. Burt, and J. R. McDonald, "Analysis of transient stability enhancement of LV-connected induction micro generators by using resistive-type fault cur- rent limiters," IEEE Trans. Power Syst., vol. 25, no. 2, pp. 885–893, May 2010.*
4. *S.-Y. Kim and J.-O. Kim, "Reliability evaluation of distribution network with DG considering the reliability of protective devices affected by SFCL," IEEE Trans. Appl. Supercond., vol. 21, no. 5, pp. 3561–3569, Oct. 2011.*
5. *S. A. A. Shahriari, A. Yazdian, and M. R. Haghifam, "Fault current limiter allocation and sizing in distribution system in presence of distributed generation," in Proc. IEEE Power Energy Soc. Gen. Meet., Calgary, AB, Canada, Jul. 2009, pp. 1–6.*
6. *S. Hemmati and J. Sadeh, "Applying superconductive fault current limiter to minimize the impacts of distributed generation on the distribution pro- tection systems," in Proc. Int. Conf. Environ. Electr. Eng., Venice, Italy, May 2012, pp. 808–813.*
7. *S.-H. Lim, J.-S. Kim, M.-H. Kim, and J.-C. Kim, "Improvement of protection coordination of protective devices through application of a SFCL in a power distribution system with a dispersed gener- ation," IEEE Trans. Appl. Supercond., vol. 22, no. 3, p. 5601004, Jun. 2012.*
8. *L. Chen, Y. Tang, J. Shi, and Z. Sun, "Simulations and experimental analyses of the active superconducting fault current limiter," Phys. C, vol. 459, no. 1/2, pp. 27–32, Aug.*
9. *L. Chen, Y. Tang, J. Shi, Z. Li, L. Ren, and S. Cheng, "Control strategy for three-phase four-wire PWM converter of integrated voltage com- pensation type active SFCL," Phys. C, vol. 470, no. 3, pp. 231–235, Feb. 2010.*
10. *L. Chen, Y. J. Tang, J. Shi, L. Ren, M. Song, S. J. Cheng, Y. Hu, and X. S. Chen, "Effects of a voltage compensation type active superconduct- ing fault current limiter on distance relay protection," Phys. C, vol. 470, no. 20, pp. 1662–1665, Nov. 2010.*
11. *J. Wang, L. Zhou, J. Shi, and Y. Tang, "Experimental investigation of an active superconducting current controller," IEEE Trans. Appl. Supercond., vol. 21, no. 3, pp. 1258–1262, Jun. 2011.*
12. *H. Yamaguchi and T. Kataoka, "Stability analysis of air-core superconducting power transformer," IEEE Jun. Trans. Appl. Supercond., vol. 7, no. 2, pp. 1013–1016, 1997.*
13. *H. Yamaguchi, T. Kataoka, H. Matsuoka, T. Mouri, S. Nishikata, andY. Sato, "Magnetic field and electromagnetic force analysis of 3-phase air- core superconducting power transformer," IEEE Trans. Appl. Supercond., vol. 11, no. 1, pp. 1490–1493, Mar. 2001.*
14. *M. Song, Y. Tang, N. Chen, Z. Li, and Y. Zhou, "Theoretical analy- sis and experiment research of high temperature superconducting air-core transformer," in Proc. Int. Conf. Electr. Mach. Syst., Wuhan, China, Oct. 2008, pp. 4394–4397.*
15. *R. Wu, Y. Wang, Z. Yan, W. Luo, and Z. Gui, "Design and experimental realization of a new pulsed power supply based on the energy transfer between two capacitors and an HTS air-core pulsed transformer," IEEE Trans. Plasma Sci., vol. 41, no. 4, pp. 993–998, Apr. 2013.*

APPENDIX

Author's Profile

Mr. Prabhakara Sharma. P obtained his Bachelor of Technology in Electrical and Electronics Engineering from ANU, Nambur, India. He completed his Master of technology in High voltage engineering from Hindustan UCE, JNTU-K, Kakinada. His Areas of Interest Induction Motor Drives, Multilevel inverters, Renewable Energy sourcesHe is currently working as Assistant Professor in Electrical and Electronics engineering in Kallam Haranadha Reddy Institute of Technology, Chowdawaram, and Andhra Pradesh, India.

Mrs. surekha vadde obtained her Bachelor of Technology in Electrical and Electronics Engineering from ANU, Nambur, India. She completed her Master of technology in Power Electronics and Drives from Hindustan University, Chennai. Her Areas of Interest Induction Motor Drives, Multilevel inverters, Renewable Energy sources. She is currently working as Assistant Professor in Electrical and Electronics engineering in Kallam Haranadha Reddy Institute of Technology, Chowdawaram, and Andhra Pradesh, India.

Mr. Murthy M.V.N. obtained his Bachelor of Technology in Electrical and Electronics Engineering from JNTU-H, India. He completed his Master of technology in High voltage engineering from Hindustan UCE, JNTU-A, Anantapur. His Areas of Interest Induction Motor Drives, Multilevel inverters, Renewable Energy sources. He is currently working as Assistant Professor in Electrical and Electronics engineering in Kallam Haranadha Reddy Institute of Technology, Chowdawaram, and Andhra Pradesh, India